BMP Planning to Address Urban Runoff Using the *SUSTAIN* Model

U.S. Environmental Protection Agency
77 W. Jackson Blvd.
Chicago, IL 60604

Research and Report-Writing Carried Out By:
Tetra Tech
1468 West 9th Street, Suite 620
Cleveland, OH 44113

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Abbreviations and Acronyms

ArcGIS	A geographic information system for working with maps and geographic information. ArcGIS is used for creating maps, analyzing mapped information, and managing geographic information in a database. ArcGIS is licensed by Esri.
BASINS	Better Assessment Science Integrating point and Non-point Sources
BMP	best management practice
BMPDSS	Best Management Practice Decision Support System
CRWP	Chagrin River Watershed Partners
EPA	U.S. Environmental Protection Agency
ESRI	Environmental Systems Research Institute
GIS	geographic information system
HUC	hydrologic unit code
LSPC++	Loading Simulation Program in C++
MPCA	Minnesota Pollution Control Agency
SUSTAIN	*S*ystem for *U*rban *S*tormwater *T*reatment and *A*nalysis *IN*tegration
SWMM	Storm Water Management Model
TMDL	total maximum daily load
TSS	total suspended solids

Executive Summary

Urban stormwater has been identified by the U.S. Environmental Protection Agency (EPA) as a contributor to impaired waters within the Great Lakes region and in other parts of the U.S. Implementation of appropriate urban best management practices (BMPs) needs to be planned and implemented to address these impaired waters. Appropriate combinations of BMPs can also be implemented to help protect watersheds as new development occurs and new impervious surfaces are created. A variety of tools have been developed to support watershed planning efforts through the evaluation and selection of viable BMP options, including EPA's System for Urban Stormwater Treatment and Analysis INtegration (*SUSTAIN*). EPA initiated a series of pilot projects in the Great Lakes Basin with the overall purpose to:

- Share information about *SUSTAIN* with Great Lakes states, communities, and watershed groups;
- Work with Great Lakes states, communities, and watershed groups to plan and implement three pilot applications of *SUSTAIN*;
- Capture lessons about BMP planning and use of SUSTAIN learned from interactions with local partners through the pilot projects;
- Develop specific recommendations on how *SUSTAIN* can effectively be used by communities and watershed organizations of all types and sizes.
- Develop additional guidance on use of *SUSTAIN*.

This project examines the applicability of *SUSTAIN* and other BMP evaluation and optimization tools in three Great Lakes watersheds: the Chagrin River in northeast Ohio; Salt Creek in northwest Indiana; and the Duluth Area in northern Minnesota. Each of the pilot projects was implemented in close collaboration with local partners and stakeholders. Full reports for each pilot project are included as Appendices A, B, and C.

Local partners appreciated SUSTAIN's ability to contribute to BMP planning processes. The pilot partners were able to provide a great deal of input and data regarding the characteristics of each of the watersheds, and identified the primary stormwater problems unique to each area. Some partners were very interested in learning how to apply SUSTAIN, whereas others were primarily interested in the final results. In general, the partners felt the tool offered a great deal of promise, especially if EPA can continue to provide technical support and address several of the challenges that emerged during the pilot work.

This report summarizes the key findings from the three pilot projects. Among the key issues discussed in the report are the following:

- ***SUSTAIN's* dependency on ArcGIS.** Incompatibility of *SUSTAIN* with new releases of ArcGIS software and the costs associated with ArcGIS licenses/software are impediments to more widespread model use. There is a need for a version of SUSTAIN that is not dependent on ArcGIS software.
- **Process for BMP Planning.** The five step process that was fashioned during the pilot projects for evaluating stormwater management opportunities and BMP combinations was found to be quite workable in varying situations, and was well-understood and supported by pilot partners.
- **Type and characteristics of BMPs.** Similar BMPs were evaluated for each of the pilots based on local partner input. Local cost data were difficult to generate. SUSTAIN outputs, particularly the performance curves which compare the relative effectiveness of various BMP combinations, were valued by the local partners.
- **Scale of model applications.** Local partners expressed interest in a model or tool that could be applied at various scales, ranging from watershed scale to very small sites. SUSTAIN works well at a relatively localized subwatershed or catchment scale; some BMP planning/watershed improvement targets may be set at relatively larger watershed scales.

- **Assumptions.** Assumptions made in setting up SUSTAIN for model runs can have significant impacts on model outputs.
- **Model documentation.** Several questions were frequently asked during the pilot projects on issues not addressed by existing model documentation. Technical notes have been developed to address many of these questions.
- **Using the internal SWMM engine with the aggregate BMP.** Local partners stated that they wanted to be able to apply an aggregate BMP (e.g., a “treatment train” approach of a rain barrel draining to a rain garden) while relying on the internal SWMM model to generate rainfall-runoff. A technical note has been developed to explain this process.
- **Project transferability.** There are several issues that need to be considered when transferring *SUSTAIN* models between users. A technical note has been developed to guide project transfers.
- **Available BMPs and design constraints.** Several new BMPs were requested by local partners that are not currently templated in *SUSTAIN*.
- **Water budget tracking.** A post-processing tool is desired to help track the water budget.
- **Cost database.** The cost database becomes outdated and requires updates on a regular basis. The existing database also lacks the input needed to generate lifecycle costs.

Section 1 of this report describes the project purpose and provides a summary of each pilot study. Section 2 provides background on the BMP optimization process and the five step process used as part of this project, and also includes a summary of the meetings and workshops that were conducted. Section 3 discusses the key findings in detail and provides preliminary recommendations.

1. Introduction

This section of the report provides background on the overall BMP planning project and its purpose, as well as summary information on the three pilot projects.

1.1 Purpose

Numerous tributaries of the Great Lakes are impaired due to problems associated with urban stormwater. Due to large areas of impervious surfaces in many tributaries, very large volumes of stormwater are discharged to area water bodies during and after storms. The volumes of water and its energy erode stream channels and shoreline areas, resulting in excessive sediment loads to the lakes, unstable riparian and shoreline areas, and degradation of aquatic biology. Natural hydrologic patterns are also disrupted, with much higher flows in wet weather (due to more runoff) and lower flows in dry weather (due to reduced groundwater recharge). In addition to the problems associated with stormwater volumes, runoff from urban and suburban areas also results in increased loads of bacteria, nutrients, metals, sediment, and other pollutants to the Great Lakes.

Implementation of appropriate urban best management practices (BMPs) which infiltrate, evapotranspire, and/or harvest and reuse stormwater need to be planned and implemented to address stormwater in these Great Lakes tributaries. BMPs are needed in watersheds that are already degraded as well as in watersheds where new development is expected. In degraded areas, siting and sizing of appropriate BMPs can reduce pollutant loadings and help restore the natural hydrology. In developing areas, BMP requirements can be established to maintain the natural hydrology and prevent increased pollutant loadings.

A variety of tools have been developed to support the selection and evaluation of viable BMP options. Many of these tools have only recently been made available and thus have a limited track record, including EPA's System for Urban Stormwater Treatment and Analysis INtegration (*SUSTAIN)*. Information about the SUSTAIN model is maintained on-line by U.S. EPA at this web address: http://www.epa.gov/nrmrl/wswrd/wq/models/sustain/. To address this knowledge gap, EPA has funded a series of pilot projects in Region 5 with the purpose of using existing BMP optimization models, including *SUSTAIN*, to assist local stakeholders with watershed planning efforts in the Great Lakes. This report summarizes the lessons learned from the initial set of these pilot projects, with other pilot projects still ongoing. The overall purpose of the project is to:

- Share information about *SUSTAIN* with Great Lakes states, communities, and watershed groups;
- Work with Great Lakes states, communities, and watershed groups to plan and implement three pilot applications of *SUSTAIN*;
- Capture lessons learned from interactions with local partners through the pilot projects;
- Develop specific recommendations on how *SUSTAIN* can effectively be used by communities and watershed organizations of all types and sizes.
- Develop additional guidance on using *SUSTAIN*.

1.2 Pilot Project Watersheds

The three watersheds that are the focus of this report are the Chagrin River in northeastern Ohio, Salt Creek in central Indiana, and the Duluth Area in northeastern Minnesota (Figure 1). Table 1 Table 1summarizes several of the key characteristics of each pilot area and additional information the pilot project watersheds are provided in the following sections; full reports for each pilot project are included as Appendices A, B, and C.

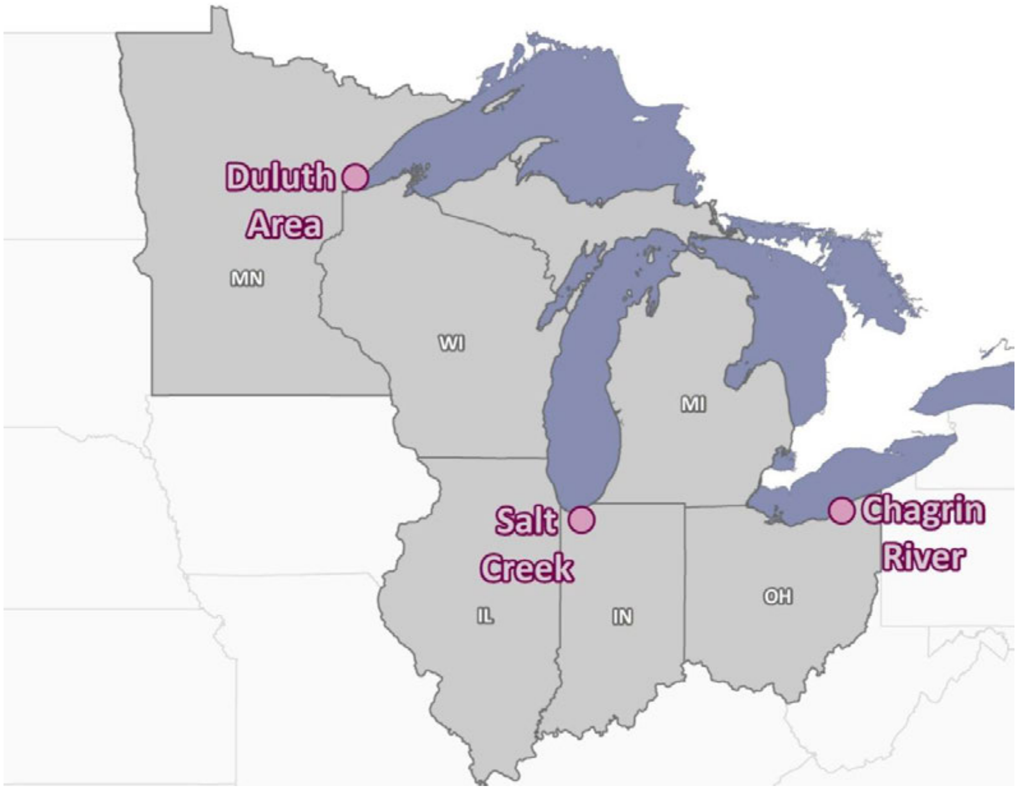

Figure 1. *SUSTAIN* pilot locations.

Table 1. Summary of pilot area characteristics

	SUSTAIN pilot		
	Chagrin River	**Salt Creek**	**Duluth Area**
Pilot Area Size (acres)	324	450	668
Imperviousness (%)	50 [a]	34	31
Rainfall-Runoff Model	LSPC++	LSPC++	SUSTAIN SWMM
BMPs Modeled			
Bioretention	Y	Y	Y
Porous Pavement	Y	Y	Y
Rain Barrels	Y	Y	Y
Cistern	N	N	Y
Detention Pond	Y	Y	N
Green Roof	N	Y	Y
Underground Storage	N	N	N
Sand Filter	N	N	N
Street Sweeping	N	N	Y
Stormwater Tree	N	N	Y
Impervious Conversion	N	Y	N
Optimization Goals	Flow volume reduction	Flow volume reduction	Total suspended solids load reduction

a Imperviousness is estimated.

1.2.1 Chagrin River Watershed

The Chagrin River drains 267 square miles in four northeast Ohio counties. The watershed is experiencing significant development pressure as the Cleveland population continues to migrate from the urban core and inner ring communities to outlying suburbs. In spite of continued farming, residential, commercial and industrial development, the Chagrin River maintains high water quality and natural beauty.

Figure 2.Chagrin River at Willoughby.

The Chagrin River Watershed Partners, Inc. (CRWP) was formed by 16 cities, villages, townships, counties, and park districts in 1996 in response to increasing concerns about flooding, erosion, and water quality problems. Major sources of impairment include land development and suburbanization, sewage treatment plants, wetland filling, removal of riparian vegetation, urban stormwater and nonpoint sources. CRWP and local stakeholders are focusing watershed management efforts on protecting existing open space, streams and wetlands; restoring those resources that have already been impacted; and influencing local development standards and practices to allow continued development while maintaining the high quality of the Chagrin River.

In 2010, CWRP began working with EPA Region 5 to test the *SUSTAIN* model. As it evolved, the *SUSTAIN* pilot application within the Chagrin River watershed focused on evaluating BMP retrofit opportunities for a large, older shopping mall. A series of performance curves were generated to provide information on the area that would need to be converted to BMPs to achieve different levels of volume reduction. The performance curves also illustrated the sensitivity of BMP performance to different design parameters (e.g., infiltration rates and storage depth).

SUSTAIN was also used for the Mentor Estates neighborhood to evaluate a variety of BMPs including three bioretention design variants, rain barrels, porous pavement, and detention pond. The maximum achievable volume control through the use of all potential green infrastructure practices within the study area was determined to be 80 percent, at a cost of more than $11 million. The most cost-effective BMPs were pervious pavement and rain gardens. Appendix A includes the full Chagrin River watershed pilot area report.

1.2.2 Salt Creek Watershed

Salt Creek is an important resource that provides recreational opportunities to the local residents of northwest Indiana. Situated in the Lake Michigan watershed with portions protected by the Indiana Dunes National Lakeshore, it is threatened by problems from stormwater runoff and erosion. The mainstem of Salt Creek is designated as a salmonid stream and is stocked for steelhead, coho, and chinook salmon.

Figure 3. Bioretention in the Salt Creek watershed.

In 2010, Save the Dunes began working with the Indiana Department of Environmental Management and EPA Region 5 to maximize opportunities to integrate ongoing TMDL, wetland, stormwater management, low impact development, and Section 319 nonpoint source management efforts on a watershed basis. The stormwater BMP planning project to test *SUSTAIN* was one component of that effort. The purpose and goals of the *SUSTAIN* pilot application within the Salt Creek watershed were to:

- Provide a summary of cost-effective BMPs that will address existing stormwater runoff problems in the Salt Creek watershed.
- Provide a summary of optimal reduction strategies for runoff volumes where development has occurred in one of the Salt Creek priority management areas, the Beauty Creek watershed.
- Provide a screening level analysis to assess the potential relative contribution to volume reduction of each BMP.

A series of BMPs were evaluated in seven subwatersheds encompassing 450 acres in the larger Beauty Creek watershed. The conversion of impervious area to pervious was used 100 percent of the time, resulting in a reduction of 4.2 acres of pavement. Porous pavement and regional ponds generally demonstrated the largest volume reductions for all scenarios in all subwatersheds. Bioretention, bioswale, and rain garden BMPs show comparable volume reduction across all scenarios. Green roofs generally exhibited the second smallest volume reductions, followed by rain barrels, which consistently provided the smallest volume reductions. Maximum BMP treatment depth (i.e., treated volume divided by the contributing drainage area) was determined to be 20 inches. This indicates that the maximum percent capture of annual average rainfall (41.8 inches) is a little under 50 percent. Appendix B includes the full Beauty Creek watershed pilot area report.

1.2.3 Duluth Area

Lake Superior coastal areas and North Shore tributary streams in the Duluth Area are threatened by problems caused by stormwater runoff and erosion, including high levels of turbidity. Lake Superior is also threatened by algae blooms, decreased clarity in the western arm of the lake, contaminated sediment in the Duluth-Superior harbor and toxic contaminants building up in the food chain. A portion of the Lakeside neighborhood in northeastern Duluth was chosen as the location for the *SUSTAIN* pilot. A drainage divide occurs within the pilot area which results in stormwater runoff being directed to Amity Creek, a turbidity impaired trout stream, as well as Lake Superior. The majority of the pilot area contains residential land uses. The topography includes steep slopes common to many Minnesota north shore stream watersheds.

Figure 4. Lake Superior and the Duluth Area pilot watershed.

The purpose and goals of the *SUSTAIN* pilot application within the Duluth Area include:

- Provide local planning information in support of addressing the turbidity impairment in Amity Creek including evaluation of water quality and flow data.
- Provide optimal reduction strategies for sediment reduction in a developed watershed in the North Shore.
- Evaluate the sensitivity of process-based pollutant removal parameters in the modeled BMPs to quantify model sensitivity to these assumptions
- Provide an example *SUSTAIN* application that utilizes the internal *SUSTAIN* SWMM engine.
- Test the flexibility of *SUSTAIN* by using new BMP types including street sweeping and stormwater trees.
- Develop a sensitivity analysis of first order decay rates for sediment removal.

A series of BMPs were evaluated in 2 subwatersheds encompassing 301 acres draining to Amity Creek and 367 acres draining directly to Lake Superior. The evaluated BMPs include: rain barrels, cisterns, stormwater trees, rain gardens, green roofs, bioretention, porous pavement, and street sweeping. The applicability of each BMP type was determined by evaluating the land uses in the watershed. *SUSTAIN* was used to determine the optimization objective of maximizing total suspended solids load reductions at the minimum cost. For the Duluth Area pilot, TSS load reductions greater than approximately 50 percent result in less treatment per dollar spent compared to reductions of less than 50 percent. In this case, rain barrels, rain gardens and porous pavement are the most cost-effective BMPs to reduce sediment loadings. Street sweeping is also a cost-effective BMP at lower TSS reduction targets (e.g., 15 and 30 percent). Appendix C includes the full Duluth Area watershed pilot area report.

2. Technical Approach

This section of the report summarizes the technical approach that was used to conduct the three pilot projects.

2.1 BMP Optimization Tools

Two BMP optimization tools were utilized during this project: 1) *SUSTAIN* and 2) BMP Decision Support System.

SUSTAIN is a model developed by EPA's Office of Research and Development to evaluate alternative plans for water quality management and flow abatement techniques in urban areas (U.S. EPA 2009). A key feature of the *SUSTAIN* model is its ability to evaluate numerous potential combinations of BMPs, assess performance and cost, and determine the optimal combination that meets a specified objective. *SUSTAIN* is designed to support practitioners in:

- Developing cost-effective management plans for stormwater programs;
- Evaluating and selecting BMPs to achieve loading targets set by a TMDL or water quality target;
- Identifying protective management practices and evaluating pollutant loadings for source water protection; and
- Selecting cost-effective green infrastructure measures to help meet optimal flow reduction goals in combined sewer overflow areas.

SUSTAIN Version 1.0 was released for public use in the fall of 2009. Version 1.2 was released in June 2012. The model is publically available at http://www.epa.gov/nrmrl/wswrd/wq/models/sustain/.

The Prince George's County BMP Decision Support System (BMPDSS), developed by Tetra Tech for Prince George's County, Maryland, is a modeling system that supports watershed hydrologic and water quality analysis, simulation of various stormwater BMPs, and selection/placement optimization (Prince George's County 2005). The system helps planners to determine which solution alternatives provide the greatest benefit for achieving management targets while balancing costs. The key questions that can be addressed by the analysis system include:

- What is the benefit of management?
- What is the difference between management options/scenarios including one or more practices?
- What is the difference in cost versus measures of benefit?

BMPDSS is not available online but can be obtained by contacting Prince George's County Department of Environmental Resources. Table 2 below provides a comparison of the different tools.

Table 2. Comparison of BMP optimization tools

Model component	SUSTAIN	BMPDSS
ArcGIS interface	Y	Y
BMP siting tool	Y	N
Internal rainfall-runoff simulation	Y	N
Internal pollutant loading simulation	Y	N
Simulate multiple BMPs	Y	Y
Simulate BMPs in aggregate	Y	N
Optimization routine	Y	Y

2.2 Targeting and Optimization Process

One of the key results of this project is the process that emerged as an efficient and effective way to implement each of the pilot projects. The process used in this pilot effort to evaluate stormwater management opportunities involves five general steps:

Step 1 - Establish baseline conditions
Step 2 - Identify BMPs to consider
Step 3 - Determine BMP configurations and performance
Step 4 - Estimate costs
Step 5 - Build targeting and optimization strategy

Figure 5 presents a general flow diagram of the process, identifying considerations and inputs. The process employed uses information on BMP effectiveness coupled with cost information to identify the most economical alternatives through an optimization step. The goal is to target specific implementation activities that address water quality problems related to stormwater.

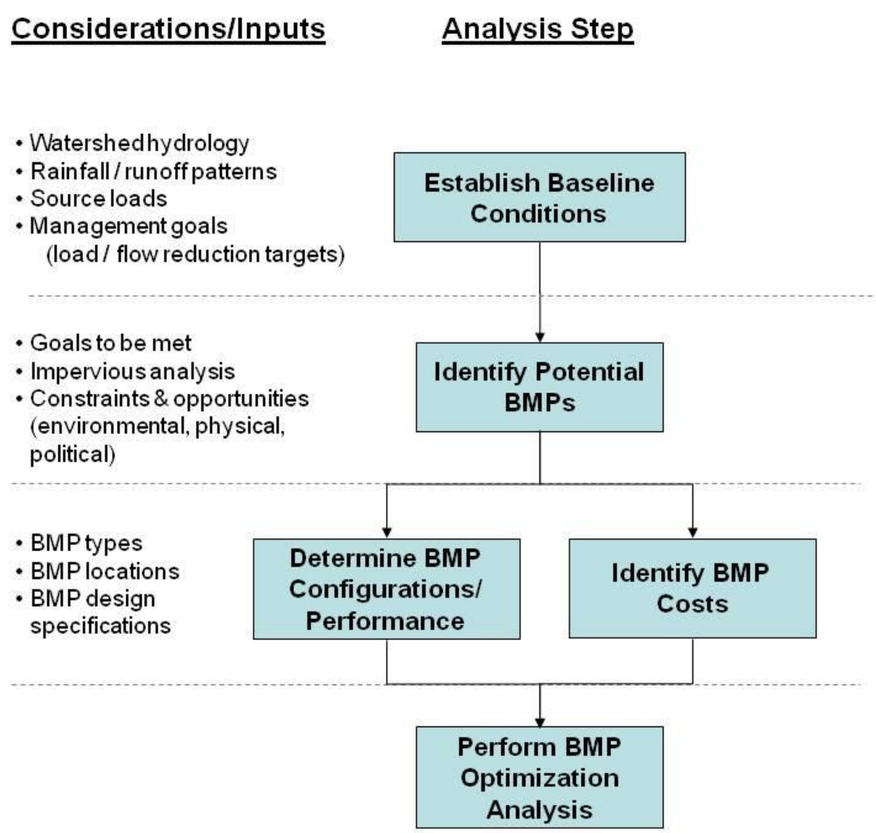

Figure 5. Process for BMP targeting and optimization.

Step 1 – Establish Baseline Conditions. The initial step in evaluating and selecting BMPs to achieve stormwater management program goals is to understand baseline conditions. Identifying baseline conditions establishes a starting point from which improvements are made and progress is measured. Baseline conditions reflect the existing flow conditions and / or pollutant loading from a stormwater source and provide a yardstick for measuring BMP effectiveness.

Step 2 – Identify Potential BMPs. Information about baseline conditions provides a benchmark that helps stormwater planners identify potential BMPs and / or combinations of BMPs to achieve overall program goals. In its simplest form, for example, the runoff volume produced by a certain design storm can be used to estimate detention needs. However, it is also important to understand other factors that might affect successful BMP implementation. These include environmental, physical, social, and political considerations. The goal of this step is to use baseline condition information coupled with local factors to generate a list of potential BMPs.

Step 3 - BMP Configurations and Performance. The goal of this step is to evaluate the list of potential BMPs and determine their overall performance at the watershed-scale. The intent is to identify options prior to selecting final BMP strategies. Assessing configuration opportunities, stormwater planners can examine the expected performance of potential BMPs to help select those that will meet the goals identified in Step 1. The stormwater planner must identify the areas that have potential for BMP placement, taking into consideration a wide range of factors such as land ownership, land use, and physical characteristics of slope, infiltration rate, and depth to water table. Although challenging, this activity is essential to selecting BMPs with the most potential for making progress toward management objectives. For purposes of describing the overall process, this is discussed as a separate step after compiling the list of possible BMPs. However, stormwater planners can make assumptions and determinations about BMP configuration and performance while generating the list.

Step 4 - Costs. Identifying BMP costs is an important undertaking for stormwater planners. Resource constraints can affect the number and type of BMPs that can be used to achieve progress toward program goals. At a minimum, stormwater planners should compare costs and expected pollutant reductions to ensure the final suite of BMPs will provide the most reductions for the least amount of money. For stormwater planners engaged in a more rigorous BMP optimization analysis, cost information on potential BMPs is essential for developing cost-effectiveness ratios (i.e., cost per unit of pollutant removed) to compare different BMPs for one type of land use or across several types of land uses.

Step 5 - Targeting and Optimization. A goal of targeting and optimization is to examine management strategies based on opportunities consistent with site suitability considerations. At this stage, stormwater planners have identified the suite of feasible BMP solutions (i.e., placement and type) based on site-specific needs, goals, opportunities and constraints. Depending on the size of the planning area, the implementation goals and the resources available, there could be any number of combinations of BMP types and locations to meet goals.

To select the final BMP strategy, stormwater planners generally evaluate, prioritize or rank the potential BMPs based on relevant decision criteria, either qualitatively or quantitatively. Decision criteria may include short-term and long-term costs, BMP performance, expected progress toward watershed goals, and compatibility with other planning priorities and objectives. Depending on the area and number of BMPs needed, a stormwater planner might use a qualitative evaluation of potential BMPs and targeted locations based on professional and local knowledge. For smaller watersheds with limited BMP options, simple spreadsheet analysis could be employed to identify the most appropriate and cost-effective scenario. For larger and more complex watershed management plans, the selection of the most cost effective and optimal solution is not easily derived. Optimization processes where a large number of alternates and combinations are explored, assists the stormwater planner in selecting and recommending solutions and capital spending priorities. Therefore, the level of detail for the evaluation to select final BMPs can be driven by the benefit of the additional analyses compared to the potential costs to correct ineffective implementation.

2.3 Information Gathering

This project was implemented in close collaboration with the local partners associated with each of the three pilot projects. The local partners were responsible for assisting with data collection and for providing input and feedback on the BMP optimization tools and the use and applicability of these tools (Table 3). Numerous meetings were held with each stakeholder group throughout the duration of the project. The meetings provided an opportunity to work with watershed stakeholders to understand the key issues in each watershed, to learn about how they currently prioritize BMP selection and placement, and to obtain their feedback on the optimization tools. Stakeholders provided input on the targeting and optimization process, evaluated the usefulness and applicability of *SUSTAIN*, and provided feedback that was used to generate much of the Findings section of this report (Section 3).

Table 3. Pilot study stakeholders

Pilot study	Local stakeholders
Salt Creek	• Save the Dunes • City of Valparaiso • Porter County • Town of Chesterton • Indiana Department of Environmental Management
Chagrin River	• CRWP • City of Mentor • Ohio Department of Natural Resources • Ohio Environmental Protection Agency
Duluth	• Minnesota Pollution Control Agency • City of Duluth • University of Minnesota Duluth – Natural Resources Research Institute • SeaGrant • EPA Mid-Continent Ecology Division (Duluth)

Stakeholder involvement for the Salt Creek pilot involved ongoing discussions with Save the Dunes to determine how BMP planning could support TMDL development and integrated watershed planning efforts. A meeting with local stakeholders was held in August 2010 to provide an overview of *SUSTAIN* and to solicit input on the project. Save the Dunes, the City of Valparaiso, and Porter County provided spatial data and monitoring information to support development of the *SUSTAIN* pilot. Monthly phone calls and quarterly meetings were held with Save the Dunes to review project direction and progress. This included three field surveys of the project area, as well as several project update meetings in 2011 with the City of Valparaiso.

Stakeholder involvement for the Chagrin pilot involved a project kick-off call in April 2010 with the CRWP, EPA Region 5, Ohio EPA, and Ohio DNR. A follow-up meeting was held in June 2010 with CRWP to provide an overview of *SUSTAIN*, demo its use, and conduct a field review of the watershed to survey potential study areas. CRWP provided monitoring and spatial data to support development of the model. Regular phone calls and meetings were held with CRWP to review project direction and progress. This included a meeting with the City of Mentor to conduct a field survey of upper Newell Creek to review several areas of concern and challenges facing the City.

Stakeholder involvement for the Duluth area pilot included a kick-off meeting that was held in October 2011. Following the kick-off meeting, the City of Duluth and UMD-Natural Resources Research Institute provided monitoring and spatial data to support development of the *SUSTAIN* model. A project update meeting was held in June 2012 to discuss progress and obtain input on BMP design parameters and applicability. A hands-on training workshop was then held in July 2012 in Duluth. The workshop was attended by 18 individuals representing local governments, state agencies, universities, consultants, and non-governmental organizations.

3. Key Findings

During development of the three pilot studies, feedback was obtained from local partners on BMPs, the *SUSTAIN* model itself, and various aspects of model development. The ability of *SUSTAIN* to provide information critical to watershed planning elements was well supported by local partners, including the ability of *SUSTAIN* to optimize to various parameters (flow, pollutants) and to run numerous potential solutions resulting in a cost-effectiveness curve. Local partners also identified a variety of recommendations for improving *SUSTAIN*. The findings presented in this section are directly related to the three pilot projects described previously and to the local partners shown in Table 3.

Key findings on the following topics are discussed in greater detail in the following sections:

- *SUSTAIN's* dependency on ArcGIS
- Type and characteristics of BMPs
- Scale of model applications
- Model documentation
- Using the internal SWMM engine with the aggregate BMP
- Project transferability
- Available BMPs and design constraints
- Water budget tracking
- Cost database

A series of Technical Notes are provided in Appendix D, which further discuss the technical details regarding several of these findings.

Technical Note 1
Formatting the External Land Simulation

Technical Note 2
The Land Use Look-up Table

Technical Note 3
Editing the *SUSTAIN* Input File

Technical Note 4
Background Infiltration Rate Sensitivity Analysis

Technical Note 5
Catchment Configuration Sensitivity Analysis

Technical Note 6
Pollutant 1st Order Decay Rate Sensitivity Analysis

Technical Note 7
Solution to Using both the Internal SWMM Engine and the Aggregate BMP

Technical Note 8
Transferring a *SUSTAIN* project

In addition to findings derived from local partner input, inconsistencies were noted during the Duluth pilot study in the way that sediment loading was modeled within the embedded version of SWMM. Code changes were implemented in the release of *SUSTAIN* 1.2 to address these inconsistencies.

3.1 SUSTAIN's Dependency on ArcGIS

The existing *SUSTAIN* model relies on ArcGIS software version 9.3 and the Spatial Analyst extension. Two primary issues with the ArcGIS platform were identified during the course of this project:

- Incompatibility between *SUSTAIN* and new releases of ArcGIS. Environmental Systems Research Institute (ESRI) has had two software releases since the *SUSTAIN* model was developed: ArcGIS version 10.0 in September 2010 and ArcGIS version 10.1 in spring 2012. The *SUSTAIN* model extension is incompatible with both of these ArcGIS versions. Due to the fluid nature of ArcGIS software updates, having a model that relies on one particular version of ArcGIS limits the potential applicability of the model to users who upgrade their ArcGIS software or who are unable to maintain multiple versions of the software. ArcGIS users do not typically have access to older versions of ArcGIS software due to licensing constraints and associated costs.
- ArcGIS software is often too costly for watershed groups and nonprofits to obtain. While the *SUSTAIN* model is a free extension available for download from EPA's website, ArcGIS software including the Spatial Analyst extension costs $4,000 for a single user license. This cost can be prohibitive for many organizations.

Based on interactions with stakeholders during the three case studies (Chagrin River, Salt Creek, and Duluth Area), there is a need for a version of the model that is not dependent on ArcGIS software. It is important to note that the computational engine of *SUSTAIN* (the part that runs the model) is an independent module that does not depend on ArcGIS. The ArcGIS portion of *SUSTAIN* (i.e. the extension) performs the preprocessing elements associated with model setup and configuration (e.g. subwatershed delineation, network routing configuration, land use area summary, etc.). The ArcGIS code generates an input file containing all the modeling information. Users familiar with the *SUSTAIN* model input file can readily modify its contents independent of the ArcGIS extension.

Recommendation

There are several possible solutions to address this issue:

1) **Update *SUSTAIN***: The *SUSTAIN* extension code could be modified to work with newer versions of ArcGIS. This option would require monitoring of ArcGIS software development and frequent updates to the *SUSTAIN* extension. There could also be portions of the *SUSTAIN* extension that could be converted to work with newer versions of ArcGIS, such as the BMP Siting Tool. These modules could then be used independently of other *SUSTAIN* components.
2) **Convert *SUSTAIN* code***:* *SUSTAIN* could be converted to work with non-proprietary GIS or other commonly used software:
    a. *SUSTAIN* could be converted to work within the BASINS model framework (which uses the non-proprietary MapWindow GIS platform).
    b. The *SUSTAIN* computation model component could be adapted to launch within an alternative model setup framework, such as Microsoft Excel. This would require development of a spreadsheet-based interface to perform the preprocessing and model configuration in place of the ArcGIS extension.
    c. The *SUSTAIN* model could be implemented in a web-based environment or through a graphical user interface.
    d. Some components/functions of SUSTAIN could potentially be blended into SWMM.
3) **Develop Modular *SUSTAIN* components.** This option would involve the creation of a modular system with optimization tools that can be accessed without the need for GIS. Eliminating the GIS interface places added responsibilities on the modeler to derive and manage input datasets; however, as a benefit this would allow users to access the BMP optimization engine through a more readily available software package.

3.2 Type and Characteristics of BMPs

As shown in Table 1, local partners in each of the three pilots were interested in the following BMPs: bioretention, porous pavement, and rain barrels. In contrast, none of the local partners expressed an interest in evaluating infiltration basins, underground storage or sand filters. The presence of low permeability soils in each of the pilot areas was the main reason for eliminating infiltration basins and underground storage from the list of potential BMPs.

Porous pavement and bioretention/rain gardens were found to be cost effective BMPs in each of the three pilot areas. However, the optimal set of BMPs varied from one pilot to another and for different levels of performance within the same pilot. This suggests that BMP performance is dependent on the characteristics of each location such as weather patterns, soil infiltration rates, the contributing drainage area, and the maximum extent to which each type of BMP can be applied in each area.

Interestingly, local partners in the Chagrin and Salt pilots were primarily interested in optimizing to flow volume reduction rather than pollutant load reduction, even though both watersheds have approved TMDLs. Local partners in Duluth chose to optimize BMP performance to TSS load reduction, primarily because of downstream turbidity impairments.

Local partners in each of the three pilots were able to provide very limited information on BMP design specifications or costs. It is likely that although BMPs have been implemented in each of the watersheds, the local partners may not have been involved in the design or construction of the practices, and therefore would not have access to that level of detail. BMP installation costs are also quite varied dependent on the region and contractor, and maintenance costs are frequently unavailable due to a lack of historical information regarding regular maintenance of these types of practices. Where there is a shortage of up-to-date regionally relevant data on BMP specifications and costs, BMP information can be drawn from various references and resources. In entering information about BMPs into SUSTAIN it is important to be mindful of what assumptions are made. The assumptions made in setting up SUSTAIN for model runs can have significant impacts on model outputs, as the model utilizes the information entered in the optimization simulations, looking at numerous applications of the BMPs and thus magnifying the effects of the assumptions.

Local partners as well as the state agencies and U.S. EPA expressed a strong degree of support for the five step process that was employed in this project to guide the BMP evaluation and optimization process. This process offers a structured framework for organizing information and conducting BMP planning which had not been considered before. Indeed, anecdotal information obtained during the course of this project indicates that the BMPs built in the three watersheds resulted from interested landowners or grant submittals rather than as a result of a concerted planning effort.

Local partners and state agencies also found the performance curves to be at least as useful as the cost-effectiveness curves. The performance curves allow local partners to easily compare the relative effectiveness of different BMPs, highlight which design parameters and assumptions are important and may require additional investigation, and provide a simple graphic which summarizes the benefit of varying levels of implementation. An example performance curve is shown in Figure 6, which illustrates the use of a performance curve to examine the effect of different background infiltration rate assumptions on BMP performance.

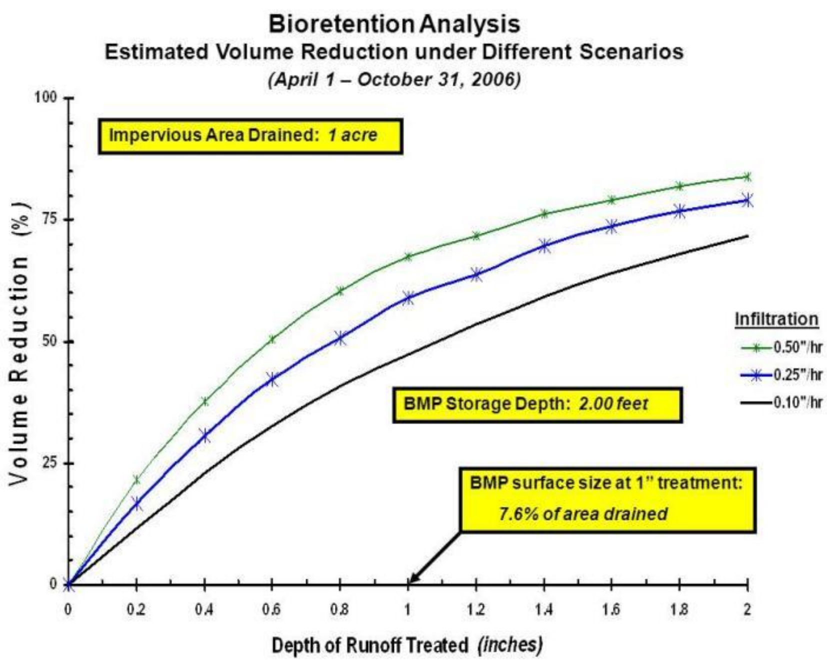

Figure 6. General BMP performance curve for bioretention.

Recommendations

Several potential recommendations emerge from these findings; note that these are subject to change based on the lessons learned from the remaining pilot projects:

1. EPA may want to provide additional information and support for the BMPs found to be of greatest interest to local partners and those that generally are found to be most cost-effective.
2. Additional information is needed on the actual performance and costs associated with retrofitting BMPs into urban areas.
3. The five-step process is an effective framework for guiding BMP selection and evaluation.
4. EPA may want to include in a future version of *SUSTAIN* the ability to directly create performance curves.

3.3 Scale of Model Applications

During development of the pilot area case studies, the issue of scale and appropriate size of pilot watersheds for analysis with *SUSTAIN* was identified as a key issue. Local partners expressed interest a model or tool that could be applied at various scales, ranging from watershed scale (HUC 12 or HUC 10; up to 250 square miles) to very small sites (less than 40 acres). *SUSTAIN* has built-in options that allow it to be configured and applied at multiple scales, but most of the applications to date have been for areas between 300 and 500 acres. Detailed analyses of potential BMPs can be assessed at this scale (e.g., counting the number of yards in which rain gardens could be placed) and a meaningful cost optimization curve can be created.

A scaled approach to using *SUSTAIN* was developed based on experiences with each of the pilot areas.

Watershed scale (HUC 10 or HUC 12)

This scale examines water quality, flow, and general land use patterns at the watershed (10-digit HUC and 12-digit HUC level). Key information that affects stormwater (e.g., rainfall-runoff relationships; distribution of pollutant loads; identification of higher density development) is used at this scale to target priority areas for subsequent analyses (e.g. catchments several hundred acres in size; groups of catchments with similar land use patterns). Delineating catchments and estimating impervious cover associated with developed land use classes are important components. The internal simulation option in *SUSTAIN* can be used to generate rainfall-runoff relationships and pollutant loadings. The watershed scale analysis allows for identification of problem areas and priority subwatersheds where implementation activities will be most beneficial. For many organizations, this level of analysis is sufficient; however coupling this with a BMP analysis at a large scale can provide for more focused implementation and programmatic recommendations.

At the watershed or subwatershed scale, the BMP assessment module of *SUSTAIN* can also be used to generate input for performance curves. These curves bracket a range of assumptions for more significant parameters (e.g., capture depth, infiltration rate) to evaluate potential BMP effectiveness. An example performance curve is provided in Figure 6. The emphasis at the watershed scale is on practices that could be applied in priority catchments, which will lead to achieving reduction targets for stormwater volume, peak flow, and / or pollutant loads. Key factors can also be evaluated affecting BMP performance. Performance curves generated can be used to target areas within priority catchments where the use of certain BMPs might be encouraged (e.g., financial incentives offered through stormwater utility credits). A simplified aggregate BMP can also be used at this scale to provide general planning level information on the effectiveness of various BMPs.

Subwatershed scale

The subwatershed scale moves to a smaller scale by further examining the mix of development and impervious cover present in priority catchments. At a subwatershed scale, the age and pattern of development can be discerned and common characteristics can be identified via air photography such as size of parking lots, street lengths and widths, number of homes, average driveway size, average roof size, sidewalk presence and size, etc. This information enables analysis to develop runoff and pollutant load estimates produced by various source areas (e.g., commercial parking, roads, residential roof). Figure 7 shows an example subwatershed scale schematic that serves as an organizational tool for the various runoff and pollutant sources. This information forms the basis of decisions to determine where certain categories of BMPs could be implemented (e.g., pervious pavement for parking, streets, and driveways; rain barrels coupled with rain gardens for residential roofs).

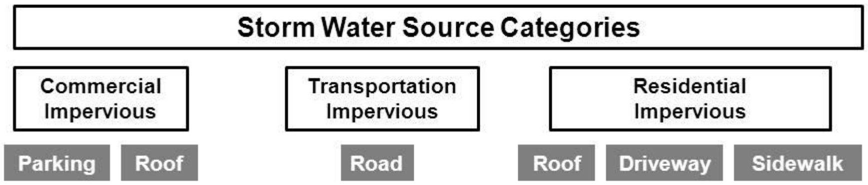

Figure 7. Stormwater source area types associated with subwatershed scale impervious cover analysis.

Because this scale of analysis is aimed at the subwatershed or catchment, the information on impervious cover is more detailed. Prioritizing the impervious areas for treatment is also a component. Pervious space should also be inventoried; both for its contribution to runoff and for consideration of potential BMPs that could be incorporated into implementation planning.

Catchment inventories enable development of estimates that describe the maximum extent to which BMPs could be applied to each impervious surface type. In addition to assessing individual practices, this scale factors in the potential use of treatment trains (e.g., rain barrels followed by rain gardens, flow from porous pavement systems to bioswales, etc.). Treatment trains can be evaluated at this scale using the aggregate BMP in *SUSTAIN*. The aggregate BMP, which assesses the combined impact of multiple BMPs, allows the user to explore the generalized impact and weigh the benefits of large scale implementation according to a general set of rules (e.g., percentage of each land use that contributes to each of the aggregate BMP components). A schematic such as Figure 7 can be used to define these rules which can then be tested using *SUSTAIN*. A subwatershed scale analysis can simply evaluate the aggregate BMP effectiveness or the analysis can be expanded to include cost and optimization features of *SUSTAIN.*

Site specific scale

A site specific scale analysis focuses in on a specific property or small neighborhood (approximately less than 80 acres). In these cases, site designs can be further evaluated beyond the subwatershed scale analysis to account for specific design considerations and potentially regulatory requirements. An aggregate BMP can be used to determine potential effectiveness of BMPs, which can then be further refined using distributed BMPs to determine the most cost-effective suite of BMPs to meet a water quality goal and standard.

3.4 Model Documentation

Several questions were raised by local partners regarding issues not addressed by existing model documentation. These questions included:

1. What is the purpose of the “look-up table” in Section 3.1.1 of the *SUSTAIN* Manual and how is it constructed?
2. How should an external time series for rainfall runoff be formatted?
3. How and when should the user edit the input files directly and what are the pros and cons to using the ArcGIS interface to generate new input files versus directly editing the input text files?
4. Are there typical ranges for input parameters that can be provided?

Recommendation

A series of Technical Notes are provided which address the first three questions:

1. Technical Note 1 provides documentation related to look-up tables.
2. Technical Note 2 provides documentation on external time series format.
3. Technical Note 3 addresses how and when to edit input files directly.

In addition to the above Technical Notes, a series of sensitivity analyses were conditioned as part of the pilot studies. Setting processed-based model parameters is almost always best approached through calibration against observed data; however, as often times quality observed datasets are unavailable these sensitivity analyses provide some guidance that can be used to estimate upper and lower boundaries for various inputs. In addition, the case studies include tables which present the model input parameters and can be used to guide other similar projects. Technical Notes 4 through 6 present sensitivity analyses for background infiltration rates, catchment configuration, and pollutant 1^{st} order decay rate, respectively.

3.5 Using the Internal SWMM Engine with the Aggregate BMP

Users would like to use the internal SWMM engine to generate rainfall-runoff time series, however, *SUSTAIN* cannot model an aggregate BMP type when using the internal simulation model.

SUSTAIN contains an embedded version of SWMM 5.0.009 that can be used to generate external time series so that an aggregate BMP can be used. Technical Note 7 provides a recommended approach that allows the user to generate rainfall-runoff time series using *SUSTAIN* SWMM while also allowing for the use of the aggregate BMP.

3.6 Project Transferability

There is a need to transfer model files between modelers and other users. Due to *SUSTAIN's* use of ArcGIS, care must be taken to ensure that files are transferred appropriately via thoughtful construction of file paths, file naming conventions and project organization. In addition, modelers may choose to edit the *SUSTAIN* model input file directly, outside of the ArcGIS environment. In these cases, the ArcGIS project will not match the final *SUSTAIN* model input.

Technical Note 8 addresses how to transfer *SUSTAIN* model files.

3.7 Available BMPs and Design Constraints

While *SUSTAIN* initially focused on BMP assessment for urban environments, during the pilot area studies stakeholders indicated a desire to apply *SUSTAIN* or a similar tool to agricultural and rural areas. There was also a desire to evaluate several BMP types not currently specified in the *SUSTAIN* model. Table 4 includes the list of BMPs currently included in the *SUSTAIN* model. While those templated BMPs can be modified and configured in different ways to address the functional behavior of other BMP types, users would like additional guidance (or new functionality as needed) to more explicitly model other regionally relevant BMPs including:

- Stormwater trees
- Constructed wetlands
- Street sweeping
- Proprietary devices (grit/swirl chambers)
- Agricultural BMPs including conservation tillage and controlled drainage
- Forest management BMPs including gravel road maintenance

Table 4. Current *SUSTAIN* BMPs

Group	BMP type
Point	Bioretention
	Rain Barrel
	Cistern
	Wet Pond
	Dry Pond
Linear	Infiltration Trench
	Vegetative Swale
	Buffer Strip
Area	Porous Pavement
	Green Roof

Recommendation

As part of the Duluth Area pilot, stormwater trees and street sweeping BMPs were evaluated. The key to parameterizing unique BMPs not explicitly called out in *SUSTAIN* is to identify and quantify the physical processes or characteristic(s) involved in flow or pollutant reduction. The following methods were employed for each of these BMPs:

- **Street sweeping** removes sediment from the land surface. From the model's perspective, this is a change to the boundary condition. The model does not currently allow boundary condition changes to be included as part of cost-benefit optimization; however, a creative work-around was applied to achieve this in the Duluth case study. It required defining different time series of TSS loading outside of the *SUSTAIN* framework to represent different frequencies of street sweeping. Next, the optimization input file for structural BMPs was rerun using different boundary conditions for street sweeping. Finally, the costs associated with each street sweeping time series were added to the optimization results to get combined cost-effectiveness curves for structural and non-structural BMPs for comparison against the existing baseline condition.
- **Stormwater trees** provide foliage for rainfall interception and increase evapotranspiration. That behavior was modeled using rainfall interception rates estimated as a function of tree size.

Other BMPs not currently built into SUSTAIN, including treatment/filtration devices, constructed wetlands, and forestry management practices are recommended for further evaluation by the *SUSTAIN* development team for potential inclusion in future versions of the *SUSTAIN* model. In addition, a street sweeping BMP should be implemented in future versions of *SUSTAIN* so that this non-structural BMP can be evaluated dynamically during optimization.

3.8 Water Budget Tracking

Tracking the water balance at various points (nodes) within a *SUSTAIN* model is critical to understanding the performance of BMPs. Because the *SUSTAIN* BMP module is processed-based, time series output of flow through each pathway is available at all assessment points. While the existing *SUSTAIN* post-processor offers a convenient framework through which to interact with the optimization results, tracking the full water balance (runoff, infiltration, evapotranspiration, storage) at the BMP level requires additional effort on the part of the modeler to parse these *SUSTAIN* time series files and summarize the individual flow pathways.

Recommendation

A post-processing tool could be developed that synthesize BMP time series output generated in *SUSTAIN* to calculate the water budget for each BMP and aggregate treatment trains as a whole. The tool would first load in BMP time series output at a user designated location. Individual BMPs could be made available in a list for the user to select. The post-processor would summarize a distribution of flows through the various BMP pathways either as: (1) outflows through the weir, orifice, or underdrain;
(2) losses to groundwater or evapotranspiration; and/or (3) flows that bypass the BMP entirely. A composite distribution of the aggregate treatment train could also be provided that shows the cumulative effects of treatment. A mockup of a possible interface for this tool is presented in Figure 8. Microsoft Excel is a convenient platform for this potential tool as it would allow for rapid development and easy integration with the existing, modular *SUSTAIN* post-processor.

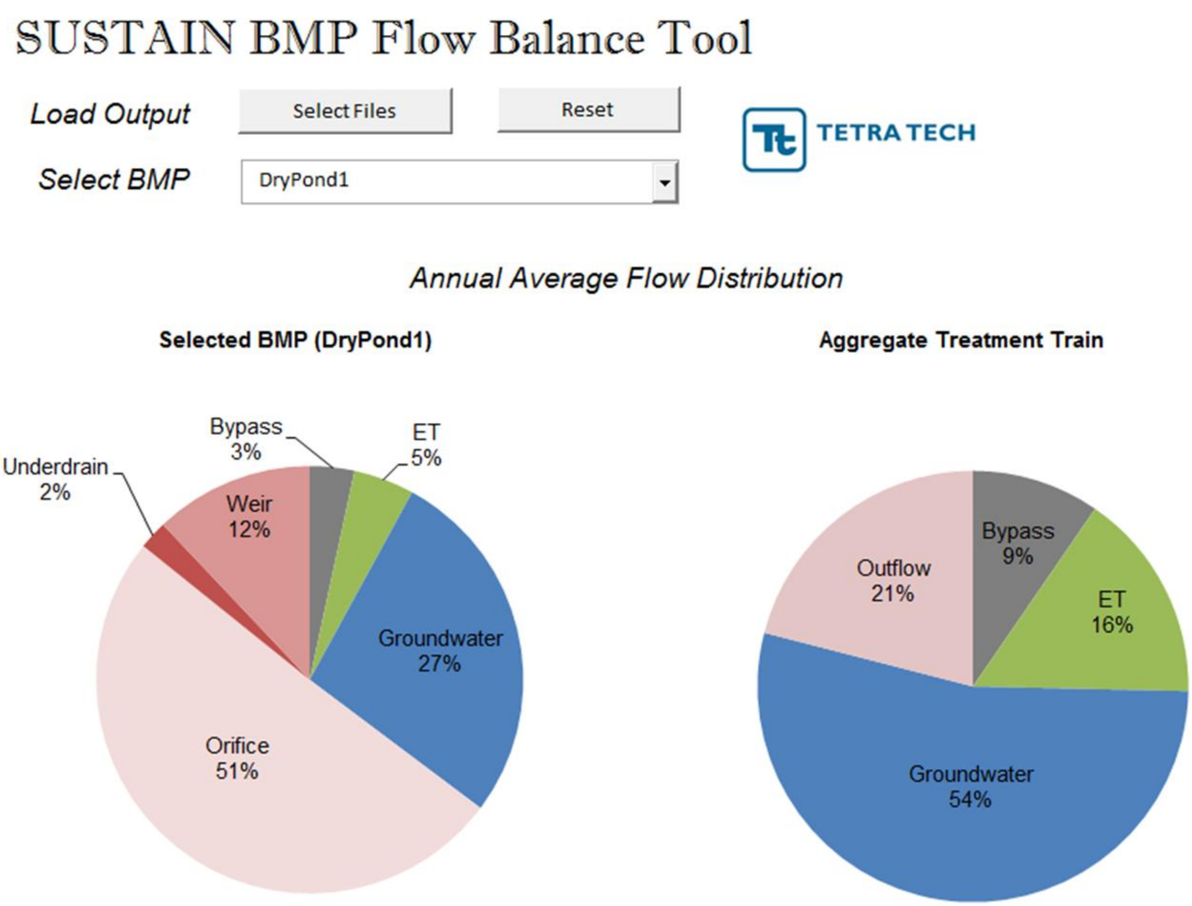

Figure 8. Mockup of a proposed flow balance post-processing tool.

In this example, a Dry Pond is selected as the BMP for analysis. Note that the BMP orifice is the primary pathway through which flow leaves the BMP; however, when the cumulative effects of the entire treatment train (which may include different BMP types such as bioretention and porous pavement) is summarized, the amount of BMP outflow decreases while losses to groundwater and evapotranspiration both increase. Only outflow and bypass from the terminal node of the aggregate network would be included in this graph to avoid double counting volume. The results presented in Figure 8 are shown as percentage of total volume; however, these could present in volumetric units and even provide results in a tabular format.

3.9 Cost Database

Cost data become outdated and require updates on a regular basis. In addition, there is a desire to evaluate the full lifecycle costs for BMPs which includes operation, maintenance, and replacement costs in order to effectively compare costs and benefits. Local BMP cost data are also difficult to generate.

The cost database included as part of the *SUSTAIN* model was derived based on a variety of data sources that were published between prior to 2009. They were intended to be available for user reference in the absence of local cost information; however, the user is always strongly encouraged to gather the most relevant and applicable cost data for their locality. Costs change over time due to inflation, new technologies in the design and construction industry, and as engineers and operators gain experience. Since green infrastructure is an evolving area of stormwater management, costs are often found to be dependent on the contractor's and owner's experience, resulting in significant variability across the Region.

Recommendation

Two options exist that will address the issue of cost inputs:

1) Frequent updates to the *SUSTAIN* cost database and inclusion of lifecycle cost data or
2) Deriving costs on a case-by-case basis using local data.

Based on input received during development of the pilot studies, local BMP cost data are often difficult to generate. This could be due to a number of reasons, but is most likely due to a limited number of green infrastructure practices being constructed in the pilot areas. Because green infrastructure projects are also being completed by numerous entities (private, watershed, city, county), no one entity has all of the cost data readily available, nor does one entity have accessible records of all green infrastructure practices being constructed. In the future, these data could be compiled by a watershed, county, or state level organization for use in estimating costs.

The pilot projects presented as part of this report (Appendix A-C) include lifecycle costs on a per foot constructed basis. These costs are based on a sum of the probable construction costs, operation and maintenance costs, and repair and renewal costs over the life of the BMP. The primary references used to derive the lifecycle costs include:

- Water Environment Research Foundation. 2009. BMP and LID Whole Life Cost Models version 2.0.
- Center for Neighborhood Technology. 2009. National Green Values Calculator.
- Weiss, P., J. Gulliver, and A. Erickson. 2005. Cost and Effectiveness of Stormwater Management Practices. University of Minnesota St. Anthony Falls Laboratory. Prepared for Minnesota Department of Transportation.
- Low Impact Development Center, Inc. 2005. Low Impact Development for Big Box Retailers. Prepared for U.S. Environmental Protection Agency.

In addition, construction costs for several projects within Region 5 were used to ensure reasonable cost estimates for the various BMPs. The costs presented in the pilot studies are based on many assumptions including site constraints, BMP design parameters, and location, and therefore should not be transferred to other projects without a thorough review for applicability.

4. References

Center for Neighborhood Technology. 2009. National Green Values Calculator.

Low Impact Development Center, Inc. 2005. Low Impact Development for Big Box Retailers. Prepared for U.S. Environmental Protection Agency.

Prince George's County. 2005. BMP / LID Decision Support System for Watershed-Based Stormwater Management: Users Guide. Prepared for the Prince George's County Department of Environmental Resources by Tetra Tech, Inc. Fairfax, VA.

Shoemaker, L., J. Riverson, K. Alvi, J. X. Zhen, and R. Murphy. 2012. Report on Enhanced Framework (*SUSTAIN*) and Field Applications to Placement of BMPs in Urban Watersheds. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-11/144, 2012.

U.S. Environmental Protection Agency (U.S. EPA). 2009. *SUSTAIN*—A Framework for Placement of Best Management Practices in Urban Watersheds to Protect Water Quality. EPA/600/R-09/095. U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC.

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